ELSEVIER

Ecological Economics 42 (2002) 469–478

ECOLOGICAL ECONOMICS

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ANALYSIS

An economic analysis of predator removal approaches for protecting marine turtle nests at Hobe Sound National Wildlife Refuge

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Received 3 December 2001; received in revised form 10 May 2002; accepted 3 June 2002

Abstract

Hobe Sound National Wildlife Refuge (HSNWR) on Florida's east coast provides undisturbed nesting habitat for three species of threatened or endangered marine turtles. Predation by raccoons and armadillos poses the greatest risk to turtle nests, and predator control has been identified as the most important management tool for enhancing nesting productivity. Recently, estimates of the number of nests that would have been lost in the 2000 nesting and incubation season were made using the results from four control approaches. These approaches were, in order of descending complexity: (1) refuge control enhanced by a one person-month contract with federal control specialists, with that control optimized using a passive tracking methodology for monitoring predators; (2) refuge control enhanced by a one person-month contract with federal control specialists, without predator monitoring; (3) refuge control, but no contract with specialists; (4) no control. In that analysis, approach 1 resulted in the fewest turtles lost to predation. In this paper, we perform a benefit–cost analysis to determine if operational efficacy translates into economic efficiency. Approach 1 had by far the best benefit–cost ratio for loggerhead turtles, but approach 2 was best for Atlantic green and leatherback turtles. However, almost 90% of the turtles nesting at HSNWR are loggerhead, and this area is vital to loggerhead survival. Thus, approach 1 also had by far the best benefit–cost ratio over all turtle species, saving approximately \$1.7 million over approach 2, \$2.6 million over approach 3 and \$8.4 million over approach 4. Given these results, one must ask how can we afford not to control predators, and furthermore, how can we not afford to take the minimal extra steps to maximize control efficacy. © 2002 Published by Elsevier Science B.V.

Keywords: Endangered species; Benefit–cost analysis; Marine turtles; Economics

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0921-8009/02/$ - see front matter
PII: S0921-8009(02)00136-2

1. Introduction

The fundamental focus of the Hobe Sound National Wildlife Refuge (HSNWR) on the east coast of Florida is to offer undeveloped and protected beach habitat for nesting by loggerhead (*Caretta caretta*), leatherback (*Dermochelys coriacea*), and green (*Chelonia mydas*) marine turtles (U.S. Fish and Wildlife Service, 1996), each of which is threatened or endangered (U.S. Fish and Wildlife Service, 1994). Prior to controlling raccoons (*Procyon lotor*) on the refuge, as many as 95% of turtle nests were destroyed annually (Bain et al., 1997). Beginning in 1988, armadillos (*Dasypus novemcinctus*) became noticeable as another primary predator of turtle nests at HSNWR (Drennen et al., 1989). Their level of predation has since risen to a similar level as that from raccoons (Bain et al., 1997). Predator removal has been carried out by refuge personnel since 1972 and has been identified as the most important management approach at the refuge (Bain et al., 1997).

The refuge in recent years has sought to improve efficacy of predator control by contracting with specialists to provide additional control of turtle nest predators. Beginning in 1999, the refuge has contracted with USDA Wildlife Services to carry out approximately one person-month of control. In 2000, the efficiency of this one person-month control budget was improved by using a passive tracking index to: (1) optimize the timing and strategy for application of control; (2) minimize labor by identifying areas where control would have maximal effect; (3) examine beach invasion patterns of predators; (4) assess control efficacy; (5) provide anticipatory information for future turtle nesting seasons; and (6) serve as a detection method for invasion by additional species known to depredate turtle nests (Engeman et al., 2001, in review). In a recent evaluation of control strategies at the refuge, this approach of concomitant predator monitoring in support of a contract with control specialists produced the highest efficacy in terms of reduced predation rates and estimated numbers of hatchlings produced (Engeman et al., 2001, accepted). However, operational efficacy does not guarantee economic efficiency. Therefore, we carried out an economic analysis of four control approaches that have been applied at the refuge.

2. Methods

2.1. Economic analysis

For the analysis we applied a benefit cost model, which attempts to determine the net benefit to the HSNWR in monetary terms, based on the gross benefits and costs given certain management techniques. Decision tree analysis, based on the four different approaches to predator management, was used to determine the optimal control technique from the standpoint of benefits versus costs from the refuge's perspective. The benefit–cost analysis (BCA) follows the framework outlined in Loomis and Walsh (1997, pp. 369–410), Boardman et al. (1996, pp. 187–205), Nas (1996, pp. 57–66), Zerbe and Dively (1994, pp. 369–394) and Loomis (1993, pp. 116–170).

The BCA of the predator approach involves estimating the monetary value of the benefits measured in turtles saved by reduced nest predation versus the costs measured in turtles lost. Determination of monetary values for threatened or endangered species is often not a straightforward or precise process. As an illustration, consider that values of endangered or threatened species have been deemed 'incalculable' in U.S. Supreme Court case law (Tennessee Valley Authority vs. Hill, 1978). Even so, conservative monetary values for rare species can be estimated through such means as costs of captive breeding projects divided by the number of healthy individuals produced (Bodenchuk et al., in press), or by minimal statutory financial penalties assessed as mitigation for illegal kills (Bodenchuk et al., in press). Captive breeding costs were not available, but in Florida, minimum monetary values (penalties) are clearly specified by statute and administrative code (Florida Statutes 370.021(5) d–f; Florida Administrative Code 39-27.002 and 39-27.011). The statutes specify minimum monetary replacement costs for marine turtles at $100 apiece, while the administrative code places the value at $500 apiece. Federal law also applies which usually imposes larger values (Endangered Species Act of 1973), up to $25,000 apiece for civil cases and up to $50,000 for criminal cases. Usually, both state and federal values apply simultaneously. For the BCA, we take a conservative approach to analyzing marine turtle values by using the $100 value specified by Florida Statute, rather than the higher values from Florida Administrative Code or the Endangered Species Act. No legislative distinction is made for minimum values among the different turtle species, nor among demographic classes (such as age) within a species. It is possible that an adult breeding female leatherback turtle might be valued in court higher than a hatchling loggerhead turtle. However, their minimum legislative values would still be $100, and our intention was to analyze the predator removal approaches in a conservative manner.

Contingent valuation is another means of assigning monetary values to species, if such survey information is available. The only such survey of which we are aware was by Whitehead (1992). He found, using an ex-ante willingness to pay survey study with supply and demand uncertainties, that individuals were willing to pay $32 per turtle for preservation. However, generalizing his study to this study would have been unlikely to be valid for several reasons. First, those results are neither temporally nor geographically applicable to the situation at HSNWR. His small sample is representative of North Carolina residents and not of Florida residents, especially of those residents in the area surrounding HSNWR. Secondly, the $32 value is a decade old and also may have been biased downward given that the survey only offered a range of turtle valuation between $1 and $100. Using the $32 value would not change the overall benefit–cost ratios, but given the specific nature of that study, it would be inappropriate to generalize and apply those results to the marine turtle situation at HSNWR.

2.2. Damage management approaches compared

We used the BCA to compare the four damage management approaches, which we specifically define from the most complex to trivial as:

Approach 1 = 2000, refuge control, contract with control specialists (approximately one person-month), spatial and temporal predator monitoring.
Approach 2 = 1999, refuge control, contract with control specialists (approximately one person-month), no predator monitoring.
Approach 3 = 1998, refuge control, no contract with control specialists.
Approach 4 = historical, no control.

Refuge control refers to the opportunistic removal of depredating animals as part of the daily duties of refuge personnel. The associated costs, while not monitored or distinguished in refuge budgets, were estimated at $3500 assuming a 10% average annual time expenditure for one ranger in these duties. The control contracts referenced in approaches 1 and 2 each cost $5000 and each comprised approximately one person-month at removing depredating animal species. Approach 1 was distinguished from approach 2 in that the animal removal was refined by spatial and temporal monitoring of predators using a passive tracking methodology (Engeman et al., 2001, accepted).

As with numerous BCA's, the costs accrue to one group (HSNWR) and the benefits (survival of the turtles) are dispersed among many. As a result of this fact the BCA is done from the perspective of HSNWR since ultimately they will bear the burden of the costs. The goals, objectives and alternatives for turtle nest protection are listed in Table 1. If all policies are equally able to meet all of the objectives then the BCR should ultimately guide decision-making.

2.3. Estimates of turtles lost through nest predation

The years 2000, 1999, 1998 had control scenarios 1, 2, 3 applied, respectively. Therefore, Engeman et al. (accepted) used the data on the number of nests for each turtle species, the average clutch size for each species, the emergence rate for each species for nests that were not destroyed by predators or other means (e.g. flooding), and the predation rates on nests of each species from 2000, 1999, 1998 (Engeman et al. accepted, Ecological

Table 1
Matrix of goals, objectives and policy alternatives for controlling marine turtle nest predators

Goal	Objectives	Policy alternatives			
		Approach 1	Approach 2	Approach 3	Approach 4
Increase turtle recruitment	Minimize the cost of nest predation from raccoons and armadillos	No	No	No	Yes
	Ensure that strategies for predation management fall within the limits of the refuges resource availability	No	Yes	Yes	Yes
	Maximise the probability of social acceptability	No	Yes	Yes	Yes

Associates, 2000, 1999), and historical high damage levels (Bain et al., 1997) to predict the number of hatchlings that would have been lost to predation had each control circumstance from the different years been applied to the turtle nesting situation in 2000. Those calculations rely on the assumption that had each control scenario been applied in 2000, the same predation rates for each species would have resulted as the year in which they were applied. The calculations can be summarized in the following equation (Engeman et al. accepted):

$$L_{ij} = N_i \times S_i \times E_i \times P_{ij},$$

where L_{ij}, the number of hatchlings of the ith species predicted lost in 2000 assuming the predation rate on the ith species nest under the jth control condition; N_i, number of nests for the ith species in 2000; S_i, the average clutch size for the ith species in 2000; E_i, emergence rate for ith species in 2000; P_{ij}, the predation rate on the ith species nest under the jth condition; i, loggerhead, green, or leatherback; j, control contract+monitoring, control contract, control without contracting with specialists, no control historical high predation. Table 2 summarizes the estimated turtle losses under the four control scenarios.

2.4. Benefit–cost model

The model reflects the costs measured in the number of turtles lost times the dollar value of the turtle, and the benefit–cost ratios for each of the different control approaches. It is assumed that these approaches are temporally independent in that they offer no cumulative effect in the subsequent year (Engeman et al., accepted). Furthermore, the dollar value was considered consistent across time periods and was not adjusted for inflation, because of the lack of normal market characteristics unique to wildlife species. It is for this reason that the different approaches can be compared across years. The basic problem facing the refuge was to determine which approach had the greatest benefit–cost ratio.

Fig. 1 displays the decision-tree analysis. To the right of the square 'policy' node there are four branches, each representing a management tech-

Table 2
The predicted number of potential hatchlings lost in 2000 at the Hobe Sound National Wildlife Refuge, Florida, due to predation when assuming the predation rates for 2000, 1999, 1998 and historical levels of predation (95%)

Year providing predation rate	Loggerhead	Green	Leatherback	Total
2000, control contract+monitoring	33,239	2957	441	36,637
1999, control contract	51,391	1960	427	53,778
1998, control without contract	56,496	5433	552	62,481
Historical high, no control	107,773	11,148	1676	120,597

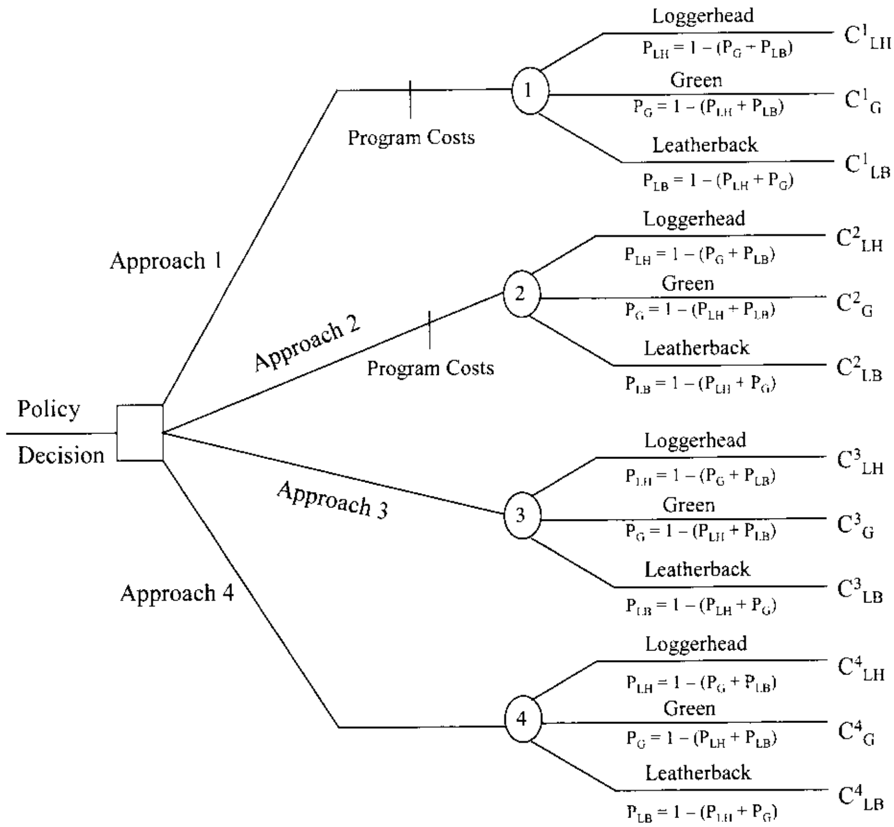

Fig. 1. Predator control approach decision tree for protecting marine turtle nests.

nique. To the right of each of these is a set of three branches representing the three different types of turtles affected: loggerhead (LH), green (G), and leatherback (LB). On each loggerhead branch is the frequency or probability of a loggerhead being lost to predation ($P_{LH} = 1-(P_G+P_{LB})$) for that approach; under each green branch is the probability of a green being lost to predation ($P_G = 1-(P_{LH}+P_{LB})$) for that approach; under each leatherback branch is the probability of a leatherback being lost to predation ($P_{LB} = 1-(P_G+P_{LH})$) for that approach. The terminal point to the far right represents the total value of turtles lost to each approach from each species, with, for example, C^1_{LH} representing the total value of loggerheads lost under the contract and monitoring approach.

2.5. Calculating benefits and costs

The objective of minimizing opportunity costs is equivalent to maximizing net benefits (Boardman et al., 1996, pp. 187–205). The benefits (B) of one approach are therefore represented as the opportunity cost of pursuing an alternate approach. The benefits of all approaches are compared to approach 4 (no predation program). For example, the benefits of approach 1 in comparison to approach 2 are the opportunity costs of approach 2. Or seen in another way, the benefits that accrue to each approach will be measured in terms of the cost saving as compared to alternate approaches. Costs (C) are measured by the number of turtles lost per species (probability × total losses per approach) times the dollar value of each turtle plus the costs of the approach. For example, the costs resulting from the loss of loggerheads under the contract and monitoring approach can be represented by the equation.

$$C^{1}_{\mathrm{LH}} = (P^{*}_{\mathrm{LH}} L_{\mathrm{T}})^{*}\$100 + \mathrm{PC}. \qquad (1)$$

where, P_{LH}, the probability of losing a loggerhead turtle; L_{T}, the total number of turtles lost; PC, approach costs ($8500 for approaches 1 and 2; $3500 for approach 3 and $0 for approach 4). Total costs accruing to a particular approach are measured by the equation,

$$C^{1} = C^{1}_{\mathrm{LH}} + C^{1}_{\mathrm{G}} + C^{1}_{\mathrm{LB}} + \mathrm{PC}. \qquad (2)$$

Therefore, C^{1} represents the total dollar value of all species lost under approach 1 (contract and monitoring) plus the approach costs. It is assumed that the program costs are divided equally across the three different species, or in other words equal effort was given to protect the turtles regardless of species.

2.6. Benefit–cost ratios (BCRs)

The BCR's are calculated using the standard format of the ratio of benefits to costs (Loomis and Walsh (1997, pp. 369–410), Boardman et al., (1996, pp. 187–205), Nas (1996, pp. 57–66), Zerbe and Dively (1994, pp. 369–394), and Loomis (1993, pp. 116–170)). For example, the basic BCR for any turtle approach is calculated from the equation,

$$\mathrm{BCR} = \frac{\text{Benefits}}{\text{Costs}} = \frac{\text{the benefits of the dollar value of turtles saved}}{\text{the costs of the dollar value of turtles lost}}.$$

The BCR's must be evaluated in terms of the other approaches available. The benefits accruing to approach 1 depend on the value of turtles lost in the alternate approaches not followed. For example, the benefits accruing to loggerheads under approach 1 in comparison to approach 2 are measured by the following equation:

$$\mathrm{BCR}^{1}_{\mathrm{LH}} = \frac{\text{the dollar value of loggerheads saved by not pursuing approach 2}}{\text{the dollar value of loggerheads lost by pursuing approach 1}}.$$

$$\mathrm{BCR}^{1}_{\mathrm{LH}} = \frac{\$5,140,766}{\$3,325,566} = 1.55.$$

In other words, the benefit of approach 1 (in lieu of approach 2) is 1.55 times greater than the cost of approach 1 for loggerhead turtles.

3. Results

Substituting the appropriate values into Eq. (1) yields,

$$C^{1}_{\mathrm{LH}} = (0.907 * 36637) * \$100 + \$2833(\$8500/\text{each turtle species}).$$

$$C^{1}_{\mathrm{LH}} = \$3,326,733.$$

Completing this process for all of the costs yield the decision tree presented in Fig. 2. This decision tree represents the costs accruing to each approach per species. Fig. 3 allows for a look at the losses accruing to each approach regardless of the species. It is evident from Fig. 3 that approach 1 offers the cost minimizing solution, however, it is

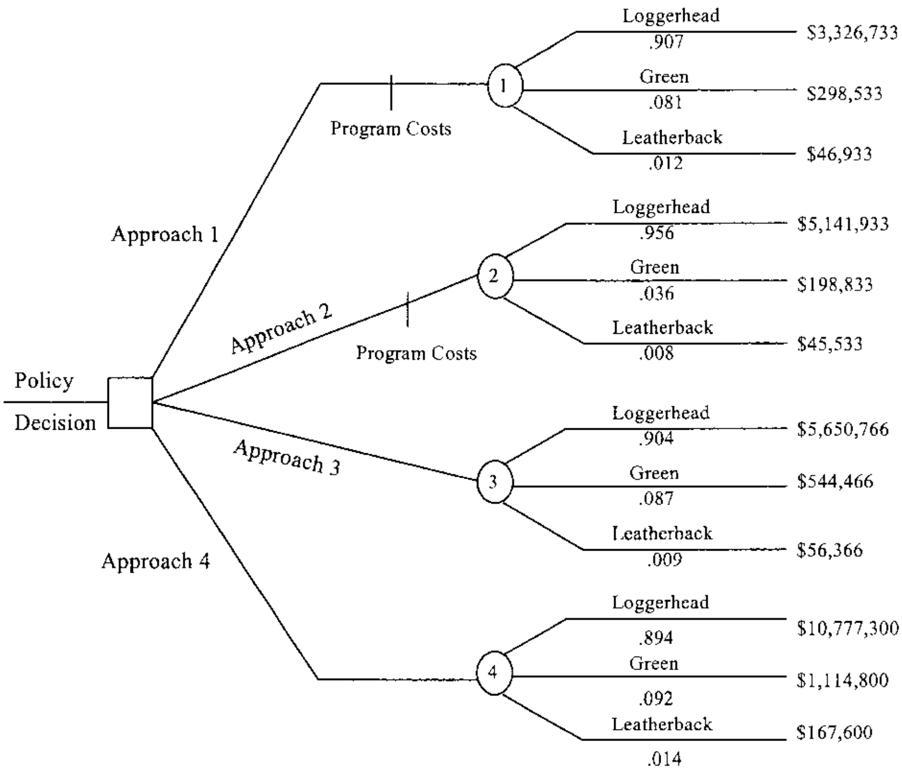

Fig. 2. Cost per marine turtle species decision tree for four approaches for reducing nest predation.

important to verify this by examining the BCR's. BCR's for all scenarios are presented in Table 3. The bolded BCR's in the table represent the best ratio's for that species. The most favorable BCR's for each species exist when approach 1, 2, or 3 is compared to approach 4 or no control. For example, the best benefit-cost ratio for green turtles is a result of following approach 2 (contract control) when compared to approach 4 (no control).

Table 3 illustrates that the approach with the most favorable BCR differs across species. For loggerheads the approach with the greatest BCR is approach 1 when compared to approach 4, but for greens and leatherbacks it is approach 2 in comparison to approach 4. However, after aggregating across species, loggerhead BCR's may be given priority over green and leatherback BCR's for two reasons. First, given the fact that loggerheads comprise the largest portion (89% in 2000) of turtle nesting concentration at HSNWR, their sheer numbers may create a situation in which approach 1 is superior when an aggregate of all species is considered (Engeman et al., accepted). Secondly, HSNWR is crucial to the survival of loggerhead turtles because it is in the center of loggerhead nesting activity in the U.S. and is substantially less vulnerable than the world's largest concentration of loggerheads located in the Middle East (Meylan et al., 1995). Therefore, a comparison of the overall BCR is needed to discern which approach is best suited for the refuge as a whole. The overall outcome of comparing the three approaches yields the results in Table 4.

It becomes clear from Table 4 that approach 1, control contract and monitoring has a greater BCR in comparison to all other possible combinations of comparisons shown by the bolded column in Table 4. In order to provide a complete understanding of the cost-saving of each program, this table shows the BCR's for each approach in

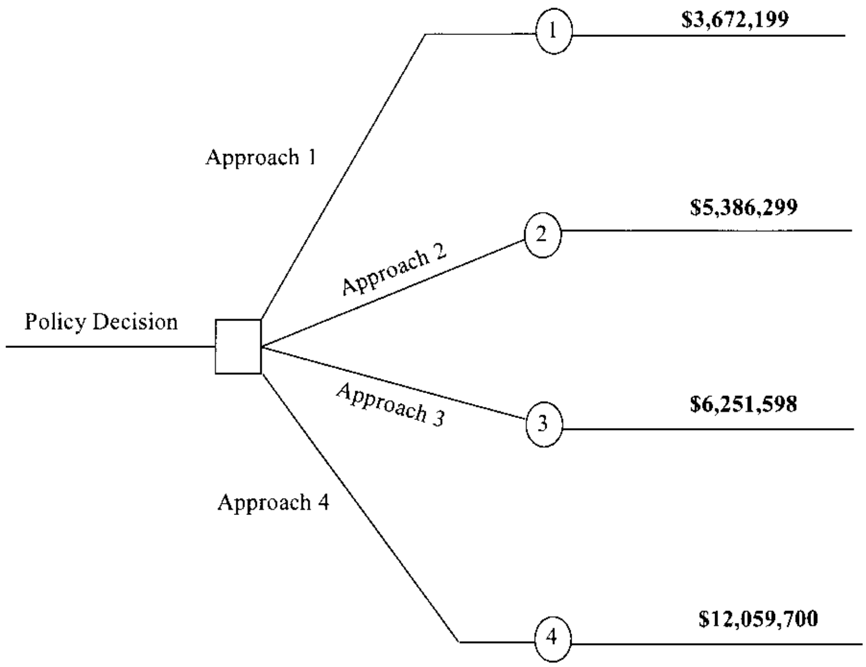

Fig. 3. Total value of Marine turtles lost under the application of four approaches for reducing nest predation.

comparison to no control (approach 4), as well as to all the other methods (approaches 1, 2, and 3). This is a strong indication that control contract and monitoring provide the most efficient allocation of resources for turtle recruitment at the refuge. Given that approach 1 is the preferred method of turtle nesting predation management, the potential cost savings represented by the value of turtles saved in comparison to other approaches is substantial (Table 5).

We performed a sensitivity analysis by differing the values of each turtle species given their status as threatened (loggerhead) or endangered (green and leatherback). The result of the earlier analysis of approach 1 having a superior BCR in comparison to approach 4 remains unaffected. Increasing the dollar value of green and leatherback turtles to $500 and keeping the value of loggerheads constant at $100 changes the best case BCR to 3.42. Increasing the dollar value of greens and leather backs to $1000 changes the best cast BCR to 3.51. In order to create a situation in which approach 1 does not yield the highest BCR, the value of green and leatherback turtles would have to be eighteen times the value of a loggerhead. Only changing the value of green turtles would require that their value be 19 times that of loggerheads to make approach 1 not the preferred method. In contrast,

Table 3
BCR's for the three marine turtle species at Hobe Sound National Wildlife Refuge and the four predator control approaches

Approach	BCR loggerhead				BCR green				BCR leatherback			
	1	2	3	4	1	2	3	4	1	2	3	4
1	1	0.65	0.59	0.31	1	1.5	0.55	0.27	1	1.03	0.83	0.27
2	1.55	1	0.91	0.48	0.66	1	0.36	0.18	0.97	1	0.8	0.26
3	1.7	1.1	1	0.52	1.83	2.75	1	0.49	1.21	1.24	1	0.33
4	**3.24**	1.91	1.91	1	3.75	**5.64**	2.05	1	3.66	**3.78**	3.04	1

Table 4
BCR for total dollar value accruing to each control approach without consideration to marine turtle species

Approach	1	2	3	4
1	**1**	0.68	0.59	0.30
2	**1.47**	1	0.86	0.45
3	**1.70**	1.16	1	0.52
4	**3.29**	2.24	1.93	1

Table 5
Dollar value of turtles saved under approach 1 versus the other approaches

Approach	Loggerhead	Green	Leatherback	Total
2	$18,15,200	−$99,700	−$1400	**$17,14,100**
3	$23,25,700	$2,47,600	$11,100	**$25,84,400**
4	$74,53,400	$8,19,100	$1,23,500	**$83,96,000**

only changing the value of leatherbacks would require a difference in value of 125 times the value of a loggerhead. Increasing the dollar value of the greens and leather backs also increases the total loss values.

Table 4 shows that the most profound dollar saving comes from pursuing approach 1 in lieu of approach 4, with an annual saving of almost $8.4 million. The total dollar saving from pursuing approach 1 over 2 is over $1.7 million, which still represents a substantial savings. Species-specific saving is greatest for loggerheads, in which a saving of approximately $1.8 million is the minimum amount saved under approach 1. This table clearly demonstrates that the pursuit of approach 1 offers significant savings in comparison to all approaches.

4. Conclusions

The results of this economic decision analysis demonstrate that, from HSNWR's perspective, a control contract and monitoring approach (approach 1) is a more cost-beneficial predation management technique with the potential to save HSNWR an average of almost $1.3 million annually in comparison to other approaches. Benefits would most likely continue to accrue for each year thereafter; however, the model used does not predict benefits beyond the short-term horizon.

From an ecological standpoint, HSNWR is located in one of most important marine turtle nesting areas in Florida (Meylan et al., 1995). The southeastern U.S. nesting concentration of loggerhead turtles is the second largest in the world. From a global perspective, this nesting aggregation is crucial to survival of loggerhead turtles because the world's largest concentration is in a Middle-Eastern region vulnerable to war, political upheaval and turmoil, and severe oil spills (Meylan et al., 1995). While the Atlantic green and leatherback turtles comprise only small proportions of the nesting concentrations at HSNWR, their populations are considered at greater risk (endangered) than the loggerhead's, and production at even small nesting sites is important. Therefore, minimization of the single greatest annual threat to the turtle nests, predation, is of great importance to the conservation of these species. Given the benefit-cost performance of any of the control efforts over no control, we have to ask ourselves how can we not afford to protect the turtle nests from predators. Moreover, given the benefit-cost performance of the monitoring plus control contract with specialists approach relative to the other tested control approaches, we must ask how can we not afford to take the minimal extra steps to maximize the beneficial impact from control.

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